Design and Implementation of a Multi-Modal Handy Speak Smart Assistive Wheelchair for Mobility and Communication

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***Abstract*—This work presents the design of a smart assistive wheelchair intended for individuals who face challenges in both mobility and verbal communication. The system aims to improve user independence while also making everyday communication more manageable. To achieve this, multiple control methods have been incorporated, including voice commands, hand gesture recognition, and smartphone-based control, allowing users to interact with the wheelchair in a way that suits their abilities. The proposed Handy-Speak wheelchair is developed using embedded system technology, integrating components such as flex sensors, ultrasonic sensors, and Bluetooth modules. An important safety feature of the system is obstacle detection, which continuously monitors the surroundings and helps prevent collisions during movement. In addition, a gesture-based speech output mechanism is implemented, enabling users to convey simple messages through predefined hand movements. The prototype was designed with a focus on usability, cost-effectiveness, and user comfort. Overall, the system demonstrates a practical solution that combines mobility assistance with basic communication support for people with physical and speech impairments.**

***Index Terms*—Assistive Technology, Smart Wheelchair, Voice Control, Gesture Recognition, Sign Language, Arduino, Ultrasonic Sensor, Embedded Systems, Bluetooth Communication, Healthcare Applications.**

I. INTRODUCTION

The Handy-Speak Smart Assistive Wheelchair is designed to support individuals who experience difficulties in movement as well as verbal communication. In many cases, conventional wheelchairs are not suitable for users who cannot operate manual controls independently, especially those who lack sufficient hand mobility. Such users often depend on external assistance even for basic movement, which limits their independence. In addition to mobility challenges, people with speech impairments face further difficulty in expressing their needs, making daily interactions more complicated.

To address these limitations, the proposed system combines mobility assistance with communication support in a single platform. The wheelchair is developed as a dual-purpose system that enables safe navigation while also helping users communicate more effectively. It offers multiple modes of interaction, including voice control, gesture-based input, and smartphone operation. This flexibility allows users to choose a control method based on their physical abilities and comfort. Along with movement control, the system also includes a gesture-based communication feature that helps convert simple hand actions into understandable outputs.

The working of the Handy-Speak wheelchair is based on embedded systems integrated with various sensors placed around the structure. These sensors continuously monitor the environment and provide real-time data, allowing the system to detect nearby obstacles and respond accordingly.

II. MATERIAL & METHODS

The Handy-Speak Smart Assistive Wheelchair is designed as an assistive system to support individuals facing both mobility and speech-related challenges. It

combines hardware and software components to function effectively in real-time conditions. The system is developed with the aim of
helping users who have difficulty in moving independently or communicating verbally by providing multiple control options while also ensuring safety during operation.

The hardware used in this project includes components such as
Arduino Uno and Arduino Nano, which act as the main control units of the system. In addition, various sensors are integrated, including flex sensors for detecting finger movements and ultrasonic sensors for identifying obstacles in the path. A Bluetooth module is used to enable communication between the wheelchair and external devices, while a motor driver controls the movement of the motors. The system is powered using a battery pack. The flex sensors are mounted on a wearable glove, allowing the system to interpret hand gestures based on finger bending. At the same time, the ultrasonic sensors continuously monitor the surroundings to reduce the chances of collision.
The software for the Handy-Speak Smart Assistive Wheelchair is developed using the Arduino IDE. The system is capable of recognizing voice commands and can also provide audio output through a speaker module. Users can control the wheelchair using hand gestures, such as simple movements that correspond to directional control. In addition, certain predefined gestures are used for basic sign-language interpretation, which can be converted into speech output. The system also allows control through a smartphone using Bluetooth connectivity, providing an alternative and convenient method of operation.
The working of the system follows a structured process where input is received, processed, and then converted into appropriate output actions. Inputs are collected from different sources, including voice commands, gesture sensors, and smartphone controls. These inputs are processed by the microcontroller, which determines the required action and sends signals to the motor driver and audio modules. Based on these signals, the wheelchair performs movement or generates sound output. At the same time, the obstacle detection system operates continuously to ensure safe navigation.
The system is designed with a modular approach, making it easier to expand and improve in the future. It consists of separate functional units such as input acquisition, processing, and output execution, each working independently while remaining interconnected. The system continuously monitors sensor data in real time, allowing quick responses to changes in the environment. This design improves overall performance and simplifies troubleshooting. It also provides flexibility to integrate additional features such as IoT connectivity or advanced control algorithms.

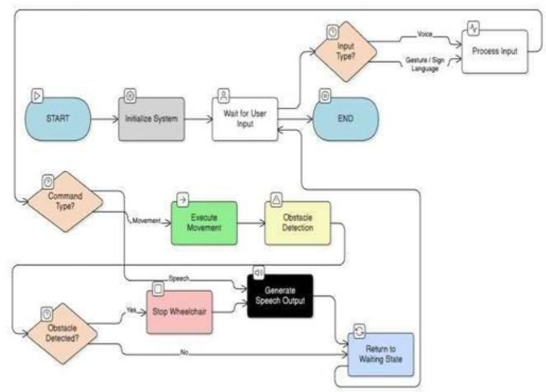

Fig.1: System Workflow of wheelchair

A. Multi-Modal Control System
The Handy-Speak Smart Assistive Wheelchair is designed with multiple control options to improve usability for different types of users. It supports various methods of interaction, allowing users to operate the system based on their comfort and physical ability. The wheelchair can be controlled using voice commands, hand gestures, and even basic sign language inputs. In addition, a smartphone-based control option is provided, which offers a convenient alternative for users who prefer mobile interaction.

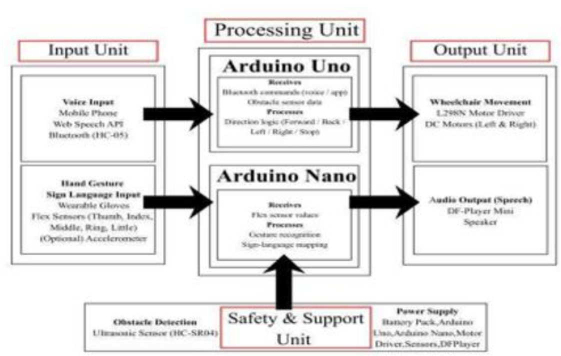

Fig. 2: Schematic Diagram of Handy-Speak Wheelchair

The Arduino Uno functions as the main control unit of the system. It receives inputs from different sources and processes them to determine the required action. Based on the processed signals, appropriate commands are sent to control the movement of the wheelchair. The availability of multiple control methods makes the system flexible and accessible, ensuring that users with different levels of physical ability can operate it effectively.

B. Gesture and Sign-Language Processing

1. Hand gestures are detected using flex sensors mounted on a wearable glove. These sensors measure the bending of fingers by observing changes in resistance. The variation in resistance is then converted into electrical signals, which are read and processed by the Arduino Nano.
2. Each recognized gesture is mapped to a specific action, such as moving the wheelchair forward, backward, left, or right. In addition to movement control, certain gestures can also be used to trigger predefined text or communication outputs.
3. For sign language to speech conversion, specific finger positions are programmed to activate corresponding audio messages. The Arduino Nano processes these inputs and sends control signals to an audio module known as the DF Mini Player, which plays pre-recorded voice messages.
4. This feature provides a simple way for individuals with speech difficulties to communicate with others through hand gestures, improving their ability to express basic needs.

C. Voice and Smartphone Control

Voice commands are first processed through a speech recognition module and then transmitted to the Arduino Uno via the HC-05 Bluetooth module. These commands are interpreted and mapped to specific wheelchair movements. This method allows users to operate the wheelchair without the need for physical interaction, making it especially useful for individuals with limited hand mobility.

In addition to voice control, a smartphone-based control method is also implemented using Bluetooth communication. The smartphone's accelerometer or an on-screen joystick interface is used to send directional commands to the wheelchair. This provides users with an alternative and convenient way to control the system based on their preference.

D. Obstacle Detection and Safety System

The wheelchair is equipped with sensors that play an important role in ensuring user safety. Ultrasonic sensors are used to measure the distance between the wheelchair and nearby objects. These sensors work by transmitting sound waves and detecting the reflected signals to determine how close an obstacle is.

When an object is detected within a certain range, the system automatically slows down or stops the wheelchair to avoid collisions. The sensors continuously monitor the surroundings, including obstacles such as furniture or walls, which helps in safe navigation during daily use. This feature improves user confidence and provides a more secure experience while moving. Overall, the system makes it easier for users to move independently and safely in different environments.

III. RESULTS & DISCUSSION

A. Prototype Development and System Integration

The Handy-Speak Smart Assistive Wheelchair was successfully developed by integrating all the required hardware components. These included Arduino controllers, motor drivers, various sensors, and communication modules. The system was able to establish proper coordination between input, processing, and output units, ensuring smooth overall operation. During testing, the wheelchair responded correctly to different control inputs and was able to move in all directions, including forward, backward, left, and right. It also stopped accurately when commands were given. These observations indicate that the individual components worked together effectively as a complete system. The results demonstrate that the proposed multi-modal control approach is reliable and practical. Overall, the system provides a useful solution to assist users in achieving better mobility and independence.

The system was tested using multiple control methods, including voice commands, hand gestures, and smartphone-based operation. During testing, the Arduino controller was able to interpret user inputs correctly and execute the required actions. Voice control allowed hands-free operation, which is especially useful for users with limited mobility. For individuals who face difficulty in speaking, gesture-based control provided an effective alternative for navigation. The smartphone interface further enhanced usability by enabling remote control through Bluetooth. In most test cases, the system responded quickly and performed the intended actions consistently across all control modes. Overall, the results indicate that the system was able to reliably understand and process commands from voice, gesture, and smartphone inputs.

Fig. 3: Handy Speak Wheelchair Prototype

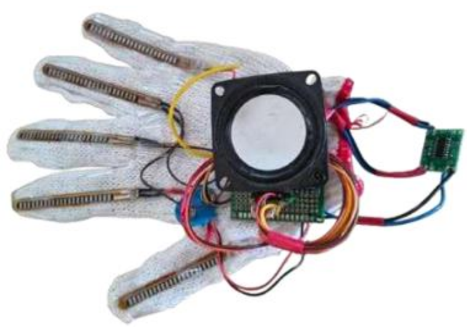

Fig. 4: Wearable Glove with Flex Sensors

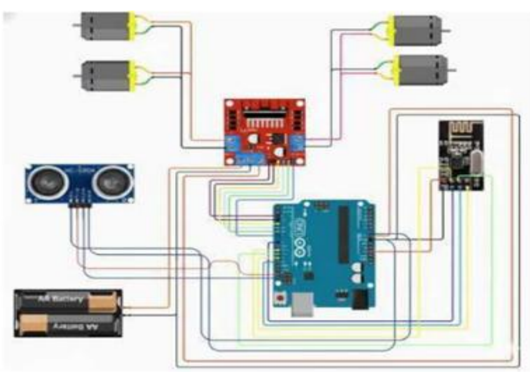

Fig. 5: Wheelchair Control Circuit

B. Multi-Modal Control Performance

The system was evaluated using different control methods, including voice commands, hand gestures, and smartphone-based inputs. During testing, the Arduino controller was able to interpret the given instructions and generate appropriate signals for motor operation. The output observed on the serial monitor confirmed that the commands were executed correctly, and the system responded as expected under different conditions.

Voice control enabled users to operate the system without physical interaction, which is beneficial for individuals with limited hand movement. For users who face difficulty in speaking, gesture-based control offered an effective alternative for navigation. The smartphone control option further improved usability by allowing remote operation through Bluetooth. Overall, the results indicate that the system performs reliably, supports multiple control methods, and provides accurate and responsive operation in practical scenarios.

Fig .6: Serial Monitor Output

C. Sign-Language Communication and Obstacle Detection

The sign language to speech feature was tested using a wearable glove integrated with flex sensors. The system was able to convert hand gestures into audible messages through the DF Mini Player and a speaker module. This functionality allows users with speech impairments to communicate basic information effectively using predefined gestures, making interaction easier in real-time situations.

The obstacle detection system continuously monitors the surroundings using sensors to identify nearby objects. It is capable of detecting obstacles within a certain range and responds by automatically stopping the wheelchair to prevent collisions. Both the communication module and safety system work together to enhance the overall usability of the wheelchair. The results indicate that the system supports safe movement and improves user confidence during operation.

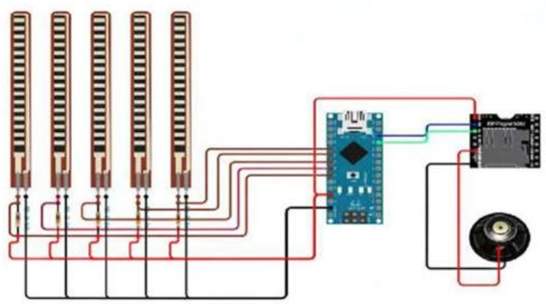

Fig .7: Sign-Language to Speech Converter Circuit

IV. CONCLUSION

The Handy-Speak Smart Assistive Wheelchair was developed to support individuals who face difficulties in both mobility and communication. The system integrates multiple features such as voice control, gesture-based navigation, and sign language to speech conversion, along with obstacle detection for safety. These functionalities work together to create a user-friendly and efficient assistive solution. During testing, the wheelchair responded accurately to voice commands transmitted through Bluetooth and successfully interpreted gestures using the wearable glove. The communication module was able to convert hand gestures into audible messages, allowing users to interact more easily with caregivers and others. The obstacle detection system also performed reliably by preventing collisions during indoor movement.

The proposed system demonstrates how different technologies can be combined to create an effective and affordable assistive device. It offers a practical solution for individuals who require both mobility support and basic communication assistance. The wheelchair can be applied in environments such as healthcare centers, rehabilitation facilities, and elderly care homes. Its ability to operate without continuous hand usage makes it especially useful for users with limited physical movement. In addition, gesture-based control provides an advantage in situations where voice commands may not be suitable. The successful development and testing of the prototype indicate that this system has the potential for real-world application, and further improvements could enhance its functionality in the field of assistive technology.

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